

Megamaser Cosmology Project: Accurate Black-hole Masses

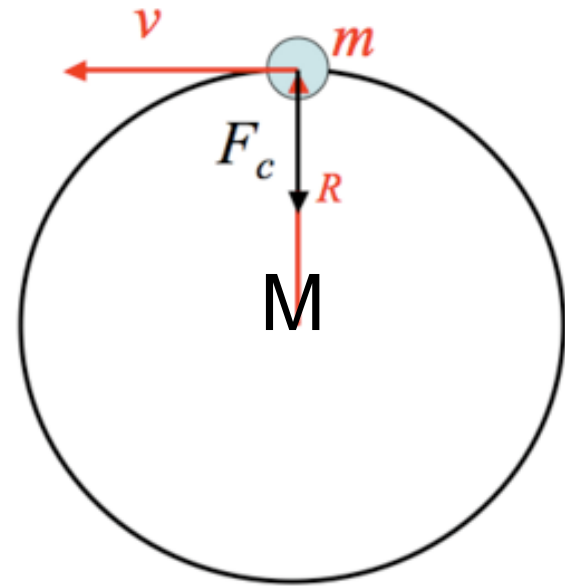
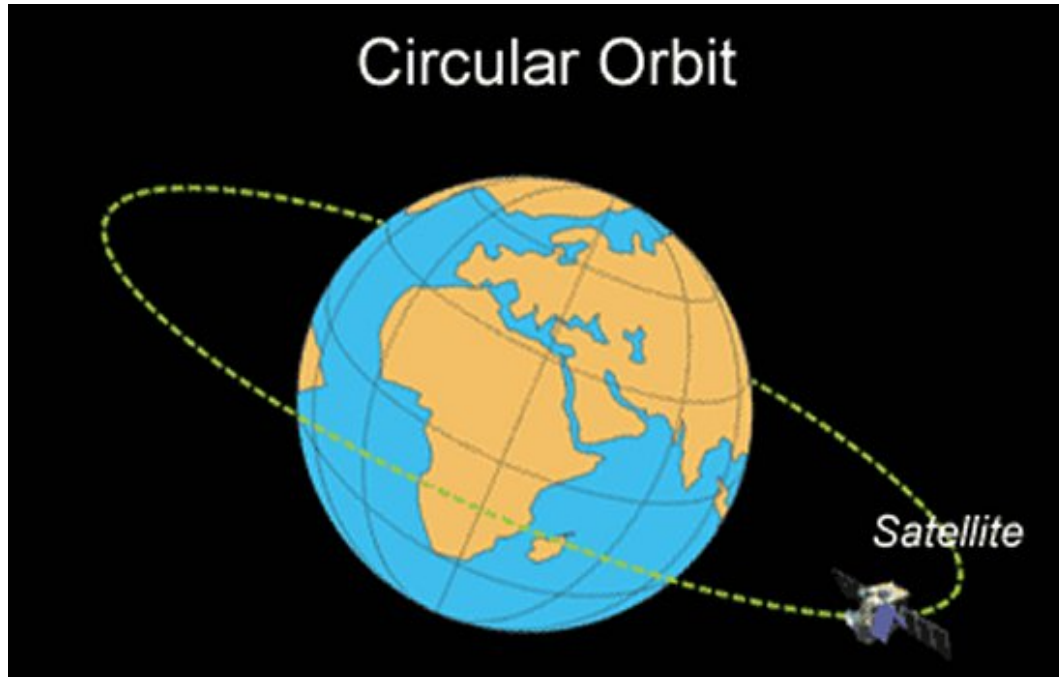


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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array



How to weigh a black hole

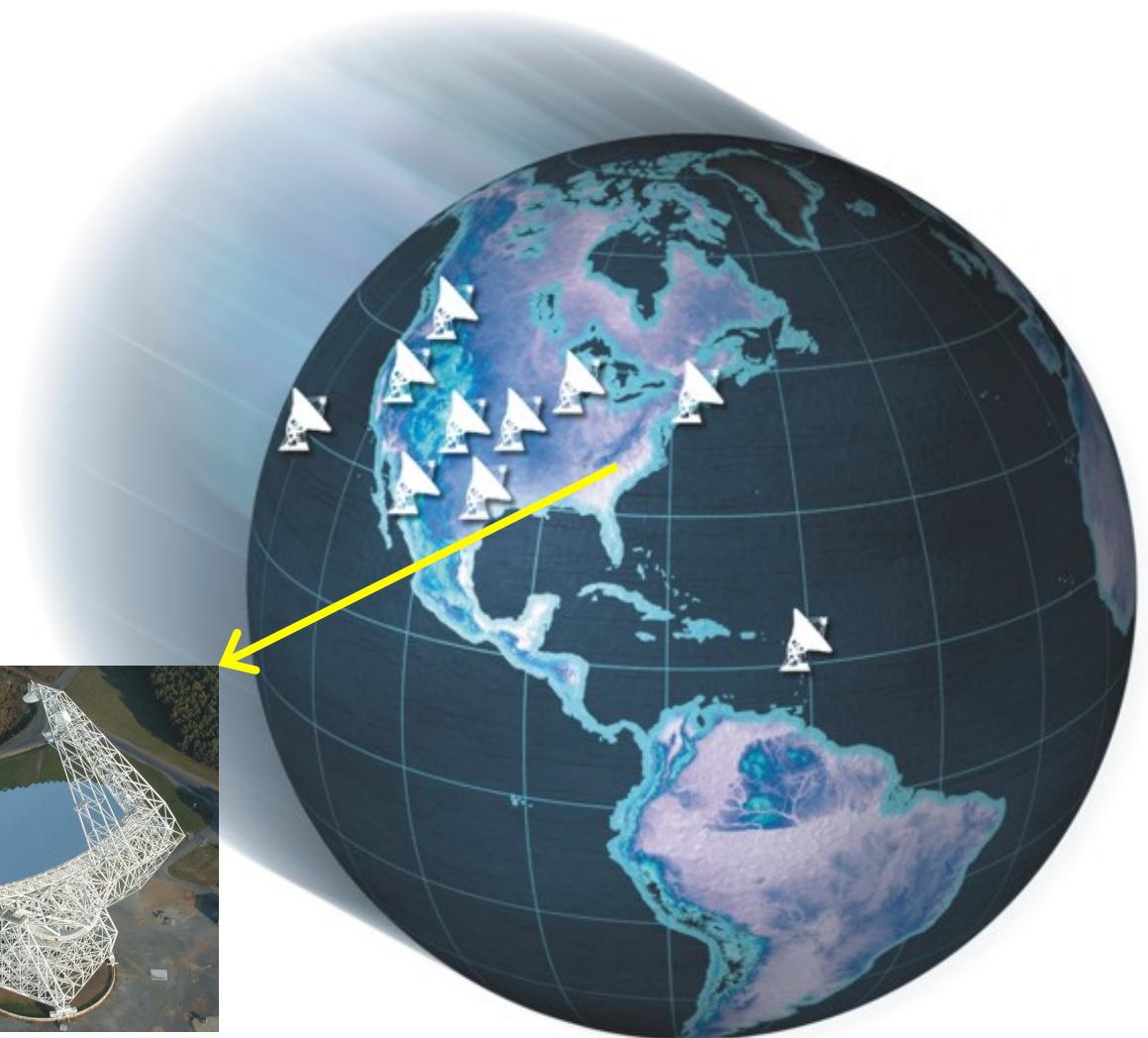


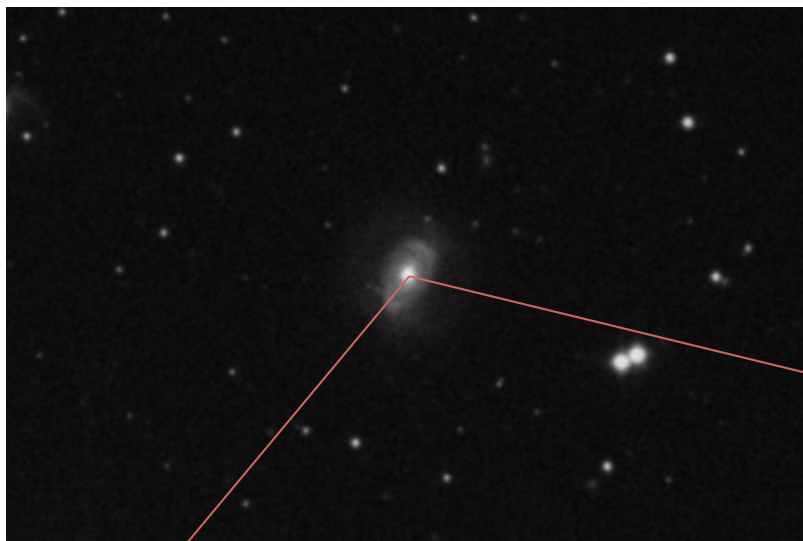
$$M = R v^2 / G \quad \text{is total enclosed mass}$$
$$R = \theta D \quad \theta \text{ from VLBA, } D = \text{Hubble distance}$$
$$v = v_r / \sin i \quad v_r = \text{Doppler velocity, } i = \text{inclination} \sim 90^\circ$$

$\lambda = 1.3 \text{ cm}$ H_2O maser imaging with the HSA = GBT + VLBA

Resolution: $\lambda / D \approx$
0.0003 arcsec

Relative astrometric
accuracy:
> 0.000002 arcsec $\approx$
 10^{-11} radians

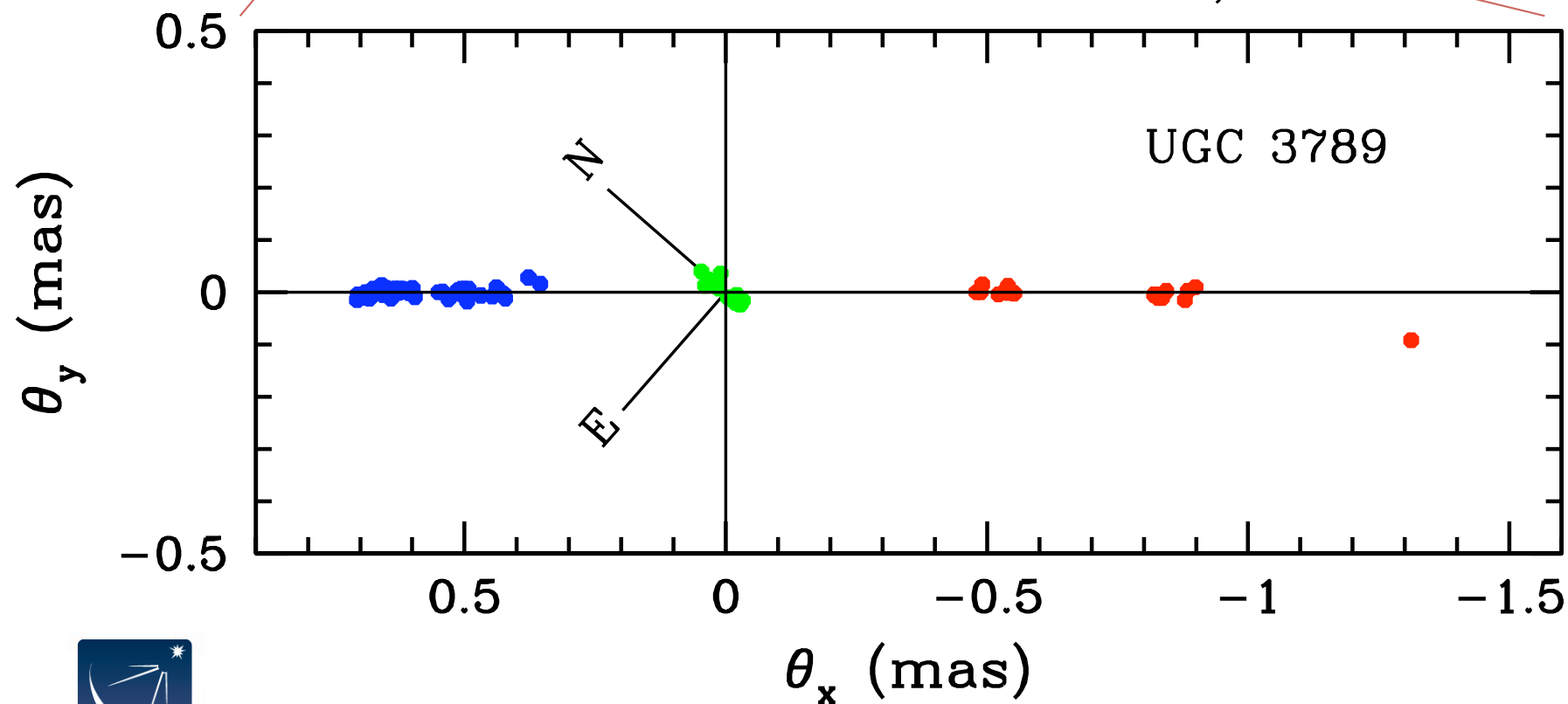


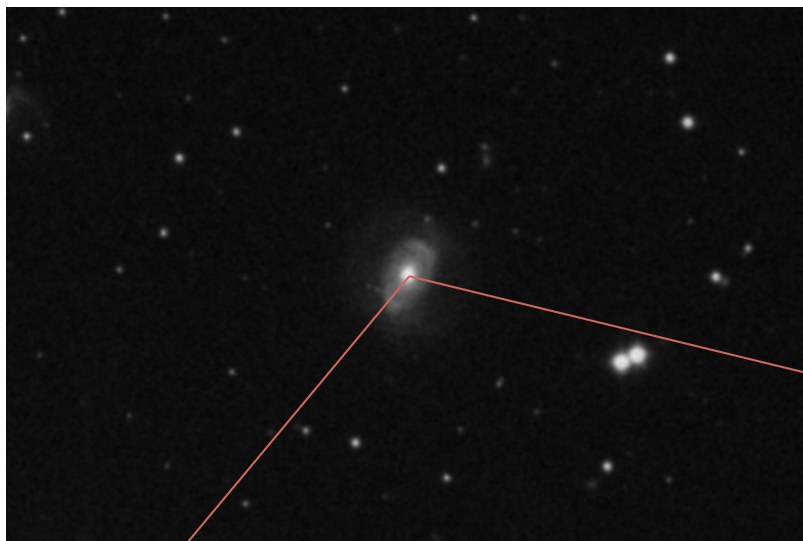


UGC 3789

D ~ 50 Mpc

Zoom 300,000 x

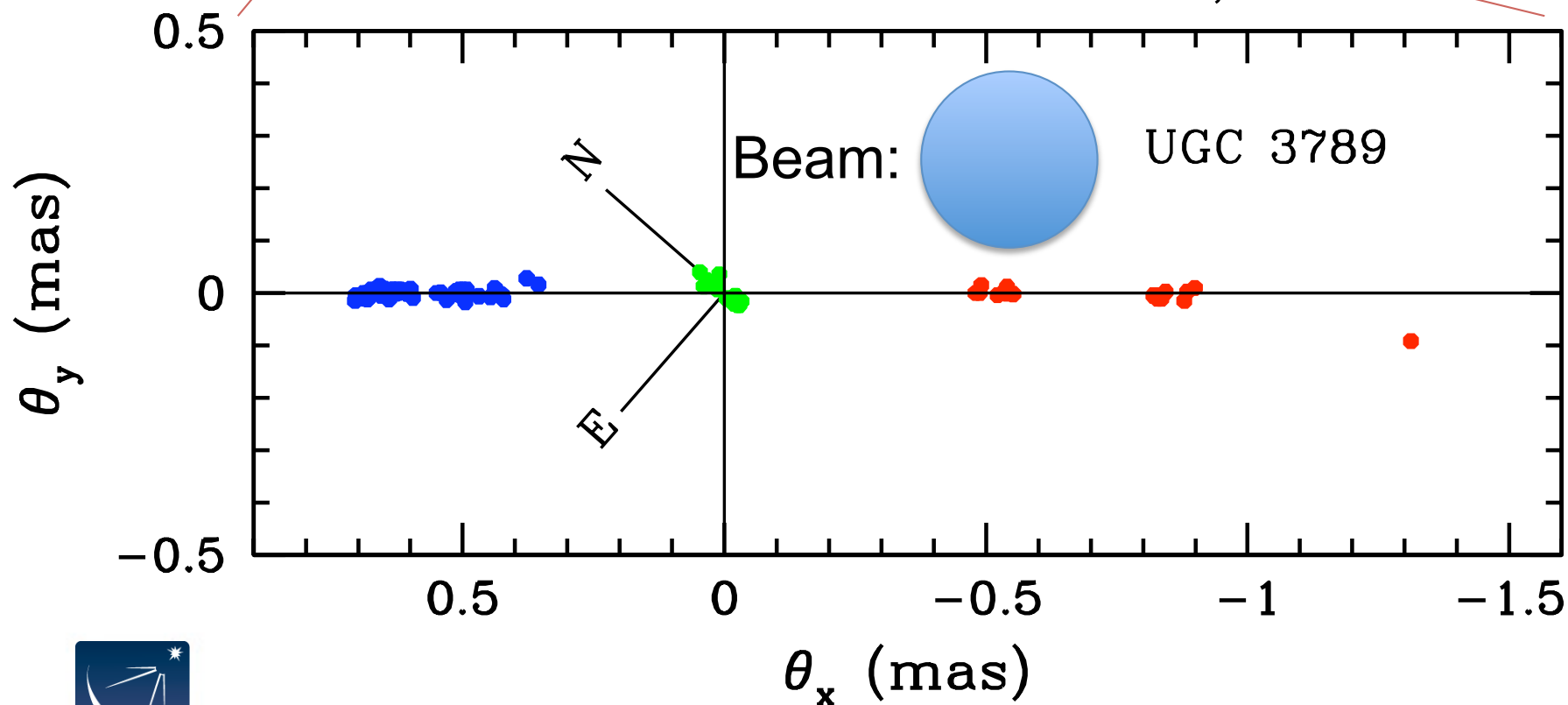




UGC 3789

D ~ 50 Mpc

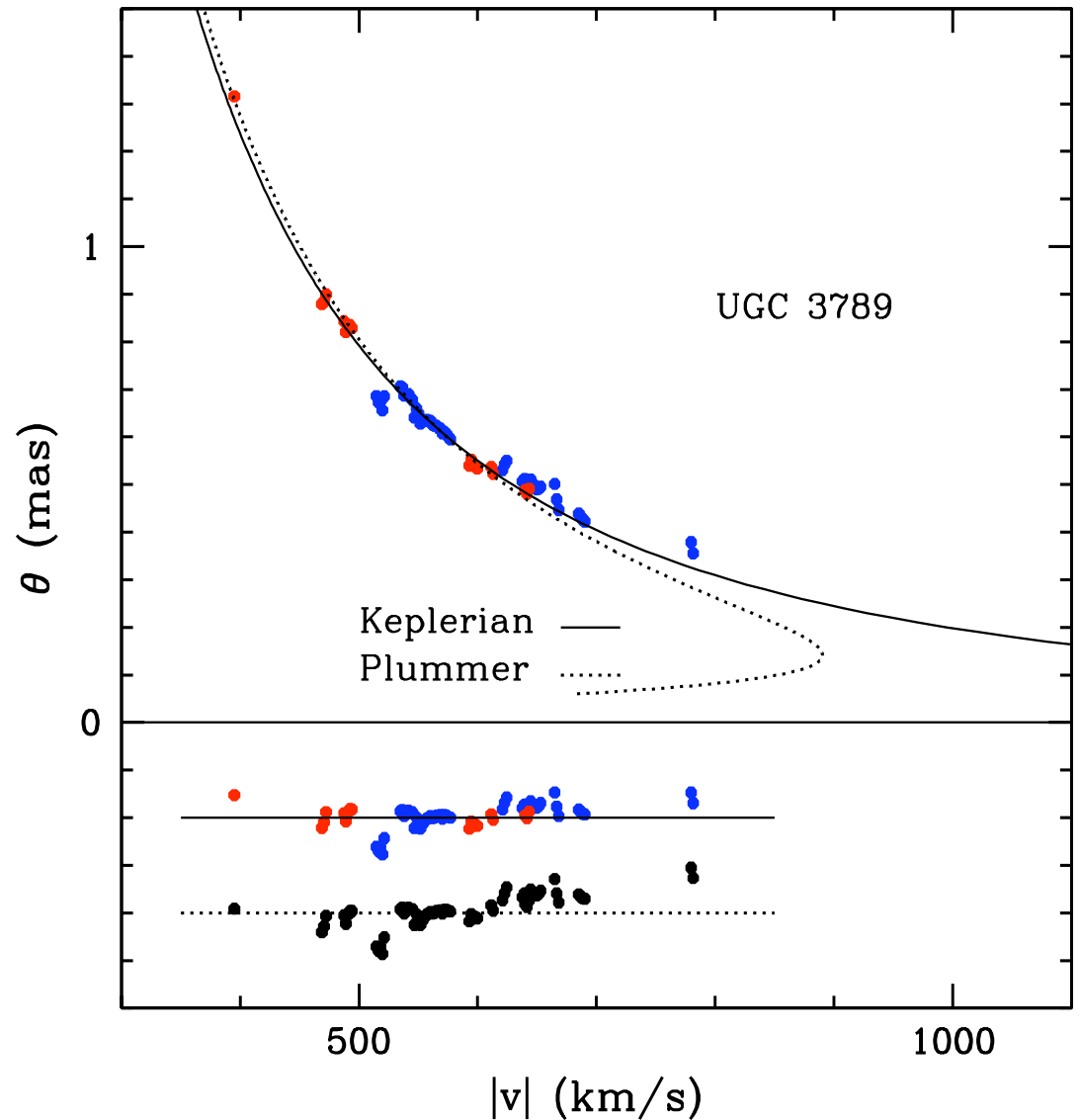
Zoom 300,000 x



UGC 3789 maser rotation curve

$D_A \sim 50 \text{ Mpc}$ so
 $0.1 \text{ mas} \sim 0.024 \text{ pc}$

$$\begin{aligned} M_* &= (v^2 \theta / G) D_A \\ &= 1.12 \times 10^7 M_\odot \\ &\times (D_A / 50 \text{ Mpc}) \end{aligned}$$

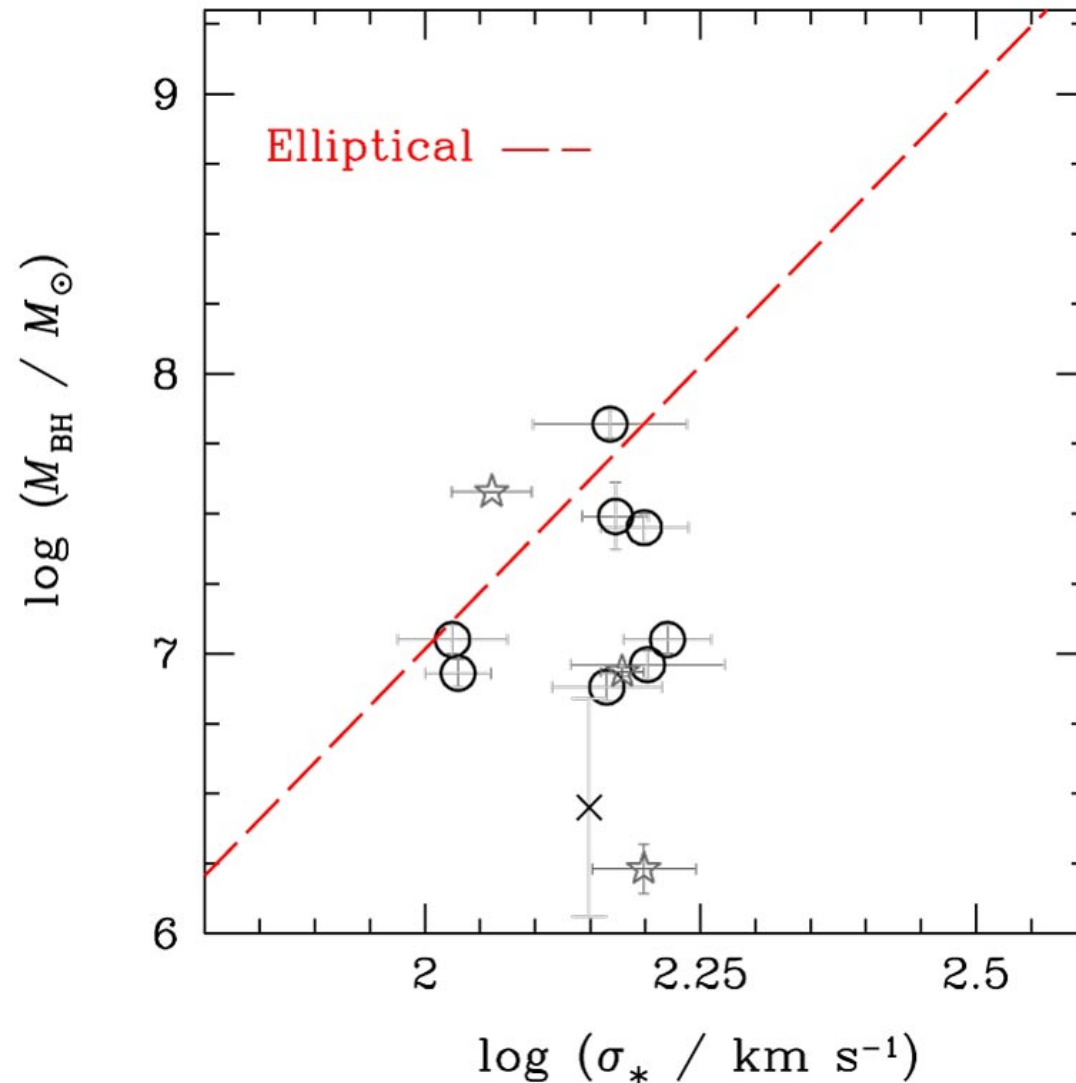


Accurate SMBH masses

Galaxy	R_{maser} (pc)	$M_{\bullet} / 10^6 M_{\odot}$
NGC 1194	0.58 – 1.41	66
NGC 2273	0.03 – 0.08	7.6
UGC 3789	0.08 – 0.30	11
NGC 2960	0.05 – 0.30	7.5
NGC 4388	0.24 – 0.29	8.4
NGC 6264	0.23 – 0.78	25
NGC 6323	0.11 – 0.29	10

Kuo et al. 2011, ApJ, 727, 20

SMBH masses in Seyfert galaxies lie below the line defined by SMBH's in elliptical galaxies



Real SMBH or just a dense star cluster?

$$\begin{aligned}\rho &= \rho_0(1+r^2/a^2)^{-5/2} \\ a &< 0.02 \text{ pc} \\ \rho_0 &\geq 4 \times 10^{11} M_\odot \text{ pc}^{-3} \\ N_\star &\geq 10^8 \\ M_\star &< 0.08 M_\odot \\ \tau &\leq 2 \times 10^6 \text{ yr}\end{aligned}$$

